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Transport energy consumption and saving in China

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ABSTRACT

At present, the global energy consumption of transport sectors is about one third of the total energy consumption of the world, such a proportion in China accounts for about 20%. Over the past decades, with the continuous development of China's economy, China's energy consumption increases rapidly, China became the world's biggest energy consumer in the year of 2009. Meanwhile, China's transport energy consumption grows greatly, and the proportion of the transport terminal energy consumption is expanding considerably.

Recently, a number of theoretical methods and technical schemes focusing on China's transport energy consumption and saving were reported. In this paper, by reviewing the existing reports, we discuss and analyze the current status of China's transport energy consumption including four different transport sectors: road, railway, waterway and civil aviation, and outline the trend of China's transport energy consumption and the four sectors. In addition, the technology status of China's energy saving in road, railway and waterway transport as well as civil aviation and their development direction are also presented. Here by analyzing the major development barriers of the technology and policy of China's transport energy saving, some related policy suggestions are proposed.

Contents

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1. Introduction

1.1. The importance of transport energy saving in China

As the global energy consumption of transport sectors is about one third of the total energy consumption of the world at present, energy saving in transport sectors has great importance, which not only involves the energy security, ecological and environment protection but also concerns the global climate change. In China, these types of problems are becoming more outstanding. As a country with the largest population and the second largest economy, the problem of China's transport energy saving has attracted the attention of the whole world.

At present, China's transport sectors are in the period of large-scale construction and development. The attendant is of increasing energy consumption and greenhouse gas emission. China needs to reduce its energy consumption and greenhouse gas emission to improve the country's environment, addressing the global climate change. The next five to ten years is the critical period for China to realize its transport energy saving as the country is accelerating its transport mode's change and developing its modern transport system.

Transport demand is closely linked to the GDP growth which strongly depends on transport energy consumption. Fig. 1 shows the results which display the total energy consumption of China's transport sectors and the country's GDP from the year 1980 to 2006 [1]. It is clear that the GDP growth rate seems to be the same as that of energy consumption. With the growth of China's GDP, it is quite necessary for China to improve its transport sectors' energy efficiency.

Realizing transport energy saving is beneficial to relieve the press of energy intensity, especially oil. According to relevant statistical data, the transport sectors consumed 52% of the total world oil production in 2005, and it is predicted that the transport sectors will consume 58% of the total world oil production in 2030 [2]. For China, its domestic oil production capacity is limited. The oil reserve per capita in China is only 3% of the world oil reserve and 5% of the world oil production capability [3]. Nowadays, China has become a net oil import country which is next to America.

For a long time, China's energy market excessively relies on coal resource. In 2006, then Chinese government proposed a new energy policy to develop diverse energy resources. Responding to the call of the government, transport sectors begin to act to make full use of the available energy resources. However, China's transport energy saving faces many reality technology and policy problems.

1.2. China's transport sectors

China's transport sectors are mainly divided into four parts, i.e., road, railway, waterway transport and civil aviation. These transport sectors undertake almost all the passenger and freight transport. In general, China's road transport occupies an important position for middle-short distance transport, and the railway plays a crucial role for long-distance transport. The waterway transport and civil aviation only undertake a small amount of traffic volume, but they play an important role in China's international transport. In contrast to other countries, such as America and Japan, there is an obvious difference between China and these countries. In America, its road transport and civil aviation undertake most of the passenger transport and its railway has the largest share in freight transport. In Japan, its passenger transport mainly relies on its railway, and its freight transport is shared by Japanese road and waterway transport.

In China, its transport sectors are managed by different administration departments. For example, the Railway Ministry is the administration department of China's railway transport, and the Transport Ministry is in charge of the highway and waterway

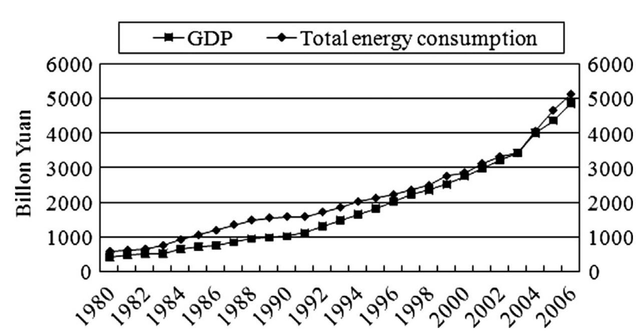

Fig. 1. Total energy consumption and GDP in China from 1980 to 2006 [1].

(including port) transport. Civil Aviation Administration is responsible for China's civil aviation. However, in cities, the vehicle administration and public transport sector belong to the Ministry of Public Security and the Department of Transportation. Other departments, such as the National Development and Reform Commission and State Environmental Protection Administration, also take part of the administration function in service prices and traffic projects approval etc. Some standards, such as the vehicle emission standard and technology standards are designed by the State Environmental Protection Administration of China.

1.3. The development of China's transport sectors

Since the end of 1980s, China began its economy and society reform. From that time, China's market demands for road transport, railway transport, civil aviation and waterway transports have been expanding. For example, between 2000 and 2007, China had a 51% increase in passenger traffic volume, and 65% increase in freight traffic volume [4]. In Ref. [5], it is estimated that in China, the average annual growth rate of passenger-turnover was 9.2%, and that of the freight transport was 10.2% between 1990 and 2006. Moreover, such an increase trend will remain for a long time. Table 1 gives the result of China's passenger-turnover and freight-turnover in 2015 and 2020. In the meanwhile, China's transport mileage also increases at a high speed. According to the official data of China, from 2010 to 2015, the transport mileage of China comprehensive transport network will have a larger growth rate (see Table 2) [6]. Rapid increase of the traffic volume results in tremendous energy consumption.

Over the past decades, China witnessed the rapid increase of the means of transport. The number of means of China's civil transport has been increasing with a larger growth rate. Table 3 gives the growth trend from 2000 to 2007. From Table 3, we can see that between 2000 and 2007, the growth rates of three different transport modes are all larger than 20%. Especially, during such a period, the population of civil car in China has a 24.41% annual average growth rate. In the future of China, vehicle population will keep a continuous growth. In Ref. [2], it is predicted that the vehicle population in China will reach the current total vehicle population in the United States by 2027–2028. Between the years of 2032 and 2036, the vehicle population in China will exceed the total vehicle population in the United States. Hu et al. estimated the vehicle population of road transport in China [4]. They reported that at the current speed, by the year 2030, the vehicle population in China will be 400 million (including 150 million motorcycles and rural vehicles). Apart from these, some researchers estimated the population of passenger cars in future which is based on different growth scenarios. For example, Li's projections are based on three economic growth scenarios (low, middle, and high) and Huo's projections are based on different vehicle diffusion rates [9,10]. In their studies, by the year of 2030, the population of total highway vehicles is about 247 (low scenario) and 287 (high scenario) million, respectively. Besides the passenger cars, there are a large number of other motor vehicles, motorcycles and rural vehicles.

Table 1
Forecasting the results of passenger-turnover and freight-turnover in China [5].

	Scenarios	2010	2015	2020
Passenger-turnover	Scenario 1	2523.45	3510.82	4778.19
(billion person-km)	Scenario 2	2557.19	3668.17	5199.94
Freight-turnover	Scenario 1	10800.73	15228.47	20911.86
(billion ton-km)	Scenario 2	10952.00	15934.12	22803.17

Table 2
Transport mileage of different transport sectors in China [6].

	Unit	2010	2015
Railway	10,000 km	9.1	12
Roadway	10,000 km	400.8	450
Waterway (Inland)	10,000 km	1.02	1.3
Urban railway	km	1400	3000
Number of civil airports		175	230

Table 3
Main means of civil transport in China [7,8].

	2000	2007	Growth rate (%)
Railway locomotive	15253	18306	20.02
Civil car	1608.91	4358.36	170.89
Civil aircraft	982	1813	84.62

In the development process of China's transport sectors, urbanization makes the urban transport problems become more outstanding. The urbanization in China makes population collected in some big cities, such as Beijing, Shanghai and Guangzhou. Moreover, the collected population is densely packed in central city zone. With the rapidly growing population, the transport demand increases sharply. From the point of view of sustainable development, Zhang et al. studied the development pattern of urban traffic system [11]. Their results indicated that since 2000, Beijing has been geared toward the way of the pattern where the percentage of each of the three modes, i.e. traveling by car, public transport and person, is less than 50%. If policy makers decide to continue the current traffic pattern, some traffic problems, such as air pollute and traffic congestions etc, will seriously affect the urban living environment and economic developments.

1.4. The aim of the paper

In the world, transport energy consumption and saving attracts increasing attentions in recent years. In the AR4 report of the Intergovernmental Panel on Climate Change (IPCC) in 2007, transport energy consumption was presented again as a major factor which has great influence on climate change [12]. Besides, a number of investigations have been conducted to address the problem of transport energy consumption and saving, focusing on transport facilities, infrastructure, policy and measures, etc. [13–24]. Ruzzenenti and Basosi evaluated energy efficiency in the European freight transport sector over three decades to determine the major drawbacks in energy efficiency metrics and identified a possible trend in the transport sector [13]. Similarly, Koroneos and Nanaki analyzed the energy and exergy utilization in the transportation sector of Greece, based on actual data, by considering the energy and exergy flows for the years of 1980–2003 [14]. In addition, researchers from the developing countries, such as Malaysia, Turkey and Jordan began to attach great importance to transportation energy consumption, as well, and explored the energy-saving modes suited to their national conditions actively [15–18].

Nowadays, concerning on China's transport energy consumption and saving, many studies have also been done. But, most of them focusing on different transport sectors, integrated studies which consider different transport sectors are few; moreover, most of the studies are technical works on China's transport energy consumption and saving, few are the integrated technology

and policy studies. In this study, by reviewing the existing studies, we comprehensively analyze the overall situation and existing problems in technology and policy of China's transport energy consumption and saving, including four different transport sectors: road, railway and waterway transport as well as civil aviation, presenting development suggestions.

2. China's transport energy consumption: current status and future trend

2.1. The general status and trend of China's transport energy consumption

2.1.1. Current status

In China's transport sectors, the absolute amount of energy consumption and the relative proportion of nationwide energy consumption are increasing year by year. According to the official data of China, in 2006, the energy consumption of transport, storage, and the postal service industries was 185.8 mtce (million tons of standard coal equivalent), which had an increase of 84.5% compared with that of 2000 [4]. From 1980 to 2006, the total energy consumption of China's transport sectors had an approximate increase of 763% [1]. From 1990 to 2006, the total energy consumption of China's transport sectors increased by approximately 309.2% which had an annual growth rate of 9.2% [5].

According to Asia-Pacific Economic Cooperation (APEC), China's transport petroleum consumption reached 98 mtoe (million tons of oil equivalent) in 2005, which is 21 times of that in 1980 [25]. Especially, the rapid growth of road vehicles and private cars had resulted in continuing growth of petroleum demand. In 2007, China's oil consumption reached 346 million tons following an increase of 61% compared with that of 2000 [4]. Fig. 2 shows the percentages of the fuel type consumed by the transport sectors in China [1]. In Fig. 2, it can be seen that in 2001, coal is nearly replaced by oil or electricity. From 1980 to 2006, the percentage of electricity and natural gas consumption were still small. However, as shown in Fig. 2, the share of the oil consumed increased from 75% to 98% between 1980 and 2006. It is estimated that in 2006, the oil supplied for transport sectors is accounted for 49.6% of the total oil consumption in China [1].

From the viewpoint of area distribution, transport energy consumption of urban area is larger than that of rural area. China's transport energy consumption of its urban area is estimated about 10–15% of the total energy consumption [11]. From the viewpoint of transport sectors, road and railway transport, civil aviation and waterway transport are the four main energy consumption systems. Zhang et al. summarized the change of the energy consumption of different transport sectors in China [1]. They reported that from 1980 to 2006, the proportion of the energy consumption by highway changed from 36.4% to 61.5%, the share of railway transport energy consumption decreased from 27.3% to 2.8%, the share of civil aviation energy consumption increased from 1.3% to 7.3%, and the share of waterway transport decreased from 32.1% to 25.6% [1]. These results are plotted in Fig. 3.

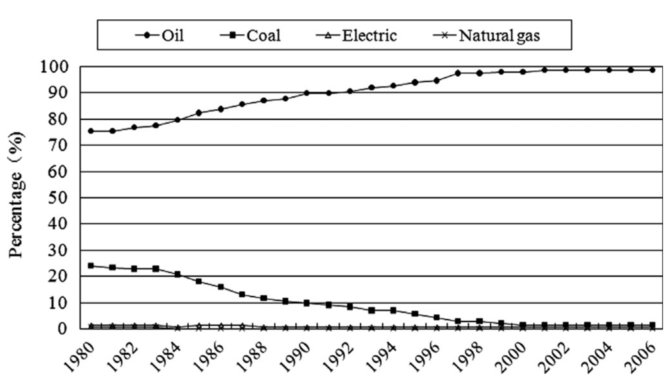

Fig. 2. The percentages of the fuel type in total energy consumption consumed by the transport sectors in China [1].

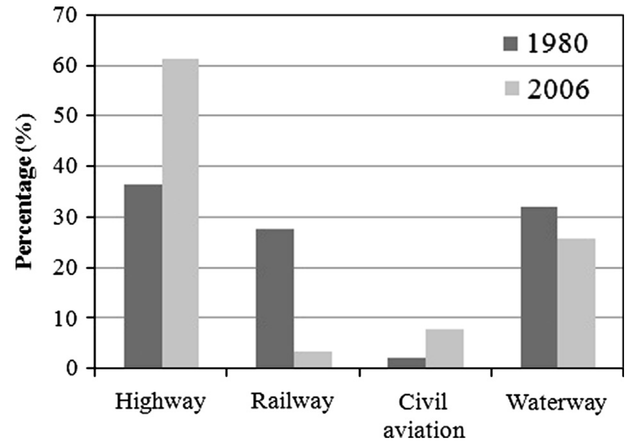

Fig. 3. The proportion change of the energy consumption of different transport sectors in China [1].

2.1.2. Future trend

Many works have been done to estimate China's transport energy demand in future. For example, in Ref. [5], Zhang et al. used partial least square regression (PLSR) method to forecast China's transport energy demand for 2015 and 2020. Here two scenarios were considered, i.e., baseline scenario and policy scenario. Their results are shown in Fig. 4. From Fig. 4, it can be seen that the future transport energy demand in 2020 is 416 mtce for policy scenario and 460 mtce for baseline scenario. This means that the transport energy demand in 2020 will be 2.33–2.51 times of that of 2006. According to such a conclusion, if no control measures are imposed to the use of vehicles in China, it will be difficult to support such large energy consumption after ten years.

Hu et al. summarized relevant statistics data, and gave a prospect of China energy demand in future [4]. It is reported that in 2030, China's total oil consumption is anticipated to reach 1152 mtce which grows with an average annual rate of 3.5%. Such a growth rate is higher than any other country in the world. According to their report, from 2004 to 2030, China's total transport energy consumption increases to more than 396 million tons, and the share of the total use of liquids fuel in transport increases from 32% to 47%. China's road, air, railway and marine transports will account for 70%, 14%, 12% and 5% of the projected energy increase in 2030 respectively.

Theoretically, the future trend of energy demand in China's transport sectors should be considered about many impact factors, such as the individual projection of vehicle population and vehicle distance traveled etc. Although a number of works have been done, different objectives, time frames, data sources and scenario designs make it very difficult to compare their results directly. But it is no doubt that since large amounts of liquid fuel are used for the transport sectors, the supplies of liquid fuels are likely in short. In the next decades, liquid fuel demand by China's transport sectors will increase continuously.

However, this does not mean that China has no way to deal with high energy demand. An extensive consensus is that fuel economy improvements in China could make a significant contribution to saving energy. For example, Hu et al. estimated that by

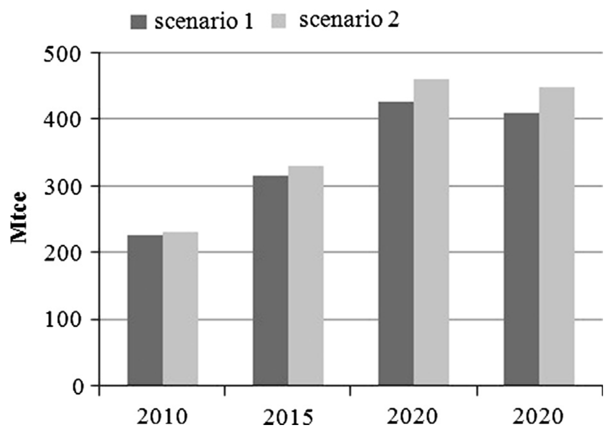

Fig. 4. Projection for China's transport energy demand [5].

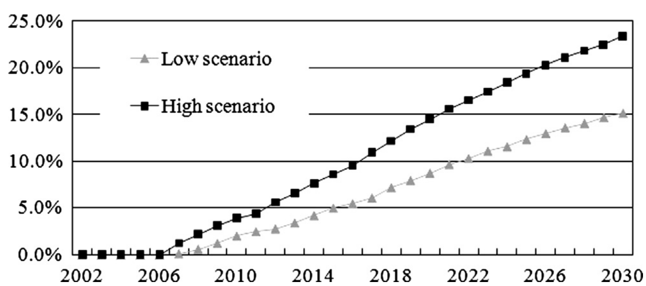

Fig. 5. Oil saving by fuel economy improvements in China [3].

2030, if fuel economy reaches Japan's present level and hybrid electric vehicle (HEV) attains 50% of the market share in China, China's transport could probably realize 42% energy saving in vehicle fuel consumption [4]. Further, if 15% of the private motorized trips are replaced by public transport, the total transport energy consumption can be saved at least 60%. In Ref. [3], He et al. estimated that in 2030, under the non-improvement scenario, oil demand by China's road transport will reach 363 million - tons which has an annual growth rate of 6.1%. If fuel economy can be improved, China oil consumption can be greatly saved in future. Their results are shown in Fig. 5. From Fig. 5, it is obvious that by 2030, the oil saving ratio will be 15% and 23% under the low- and high-improvement scenarios, respectively.

2.2. *The current status and future trend of different transport sectors*

2.2.1. *Road transport*

Because of the expanding transport demand, the energy consumption of road transport increases rapidly in China. Recently, a number of studies have been reported to explore China's transport energy consumption. These studies assessed China's energy consumption options for reducing energy consumption from different viewpoints. For example, in Ref. [26], Yan et al. not only analyzed the past energy consumption, but also assessed the effectiveness of possible measures of reducing energy consumption in China's road transport sector. In their study, a detailed model was developed to derive a reliable historical change of energy demand in China's road transport sector between 2000 and 2005. Their results are shown in Table 4. Two scenarios were designed to describe the future strategies relating to the development of China's road transport sector. One is the “Business as Usual” (BAU) scenario in which the government is assumed to do nothing to influence the long-term trends of the road transport energy demand. The other is “Best Case” (BC) scenario where a series of

Table 4
Energy demand in China's road transport sector (unit: mtoe) [26].

	2000	2001	2002	2003	2004	2005
Gasoline	36.86	38.55	40.24	43.17	46.30	49.65
Diesel	19.72	21.68	24.71	27.49	31.32	33.92
CNG	0.12	0.20	0.44	0.62	0.79	0.97
LPG	0.40	0.56	0.63	0.74	0.74	0.74
Bioethanol	0	0	0.17	0.34	0.51	0.68
Total	57.10	60.99	66.18	72.35	79.66	85.96

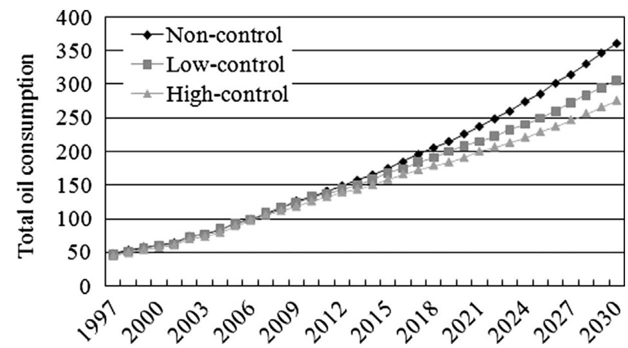

Fig. 6. Oil consumption of China's on-road vehicles (unit: million tons) [3].

available reduction measures are assumed to be implemented. As pointed in Ref. [26], in 2030, the total energy demand would reach 444 mtoe in the BAU case. Such an energy demand is more than 5 times of that of 2005. But in the BC case, as discussed in Ref. [26], the total energy demand would be 264.1 mtoe.

Cai et al. analyzed China's energy demand in future by identifying some key barriers which affect fuel consumption options in road sector [27]. Their discussions are mainly focused on technology, financial and institutional aspects. He et al. analyzed the current status of oil consumption of China's road transport sector, and further forecast the future trend of the oil demand [3]. In their study, a bottom-up model was developed to estimate the historical oil consumption between 1997 and 2002. Using the proposed model, the future trends of the oil consumption up to 2030 is forecasted. Their forecasted results are shown in Fig. 6. From Fig. 6, in future, the oil demand of China's road transport sector by motor vehicles will increase dramatically even under the high-fuel economy improvement scenario. This is because that the improvements of fuel economy will be more than offset by the rapid increase of vehicle population.

2.2.2. *Railway transport*

Over the past few decades, the energy consumption of China's railway transport sector displayed a decreasing trend. According to the recent statistical data from China Railway Ministry, in 2011, the energy consumption of China railway transport sector consumed about 17,725,000 tons of standard coal [28]. Fig. 7 shows the energy consumption of China's railway sector from 2007 to 2010. It is obvious that the energy consumption from 2009 to 2010 is less than that from 2007 to 2008. Such a result is beneficial on the measurement, called “energy saving and emission reduction” implemented by China's Railway Ministry. The core of this measurement for the railway transport sector is to enhance the supervision of energy saving, and promote the technology progress.

The future energy consumption of China's railway transport sector is given in Table 5. From Table 5, it can be seen that from

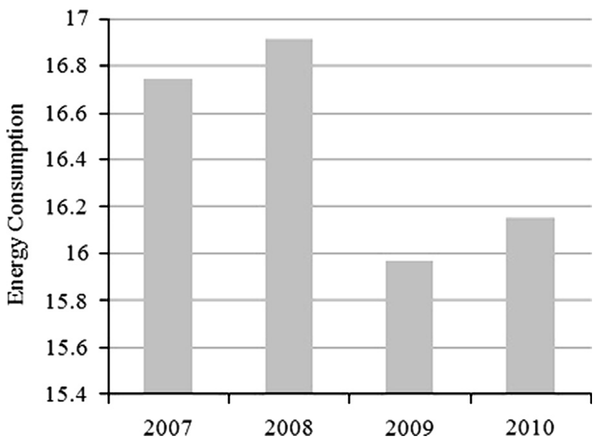

Fig. 7. Energy consumption of China's railway transport from 2007 to 2010 [28].

Table 5
Transport energy consumption prediction by sectors in China (unit: mtce) [29].

	2015	2020	2025	2030
Railways	41.54	47.93	59.64	71.36
Civil aviation	29.82	41.54	52.19	71.36
Waterways	34.08	37.28	41.54	41.54

2015 to 2030, the energy consumption of the railway transport sector increases with an average growth rate of 3.67%. Table 5 also gives the energy consumption of different transport sector of China in future. It is clear that the average growth rate of the railway transport sector is larger than that of the waterway transport, but is smaller than that of the civil aviation and highways transport.

The percentage of the energy consumption of locomotives to the total energy consumption in the railway transport of China is around 89% [30]. He et al. analyzed and discussed some valuable data on the current status of the energy consumption of the locomotives in China's railway sector [31]. Here it is obvious that although the volume of passengers and freight continuously increased from 1975 to 2007, the total energy consumption of the locomotives decreased. This is because that the efficiency of energy utilization is improved greatly in China's railway transport sector. Not only the locomotive traction by diesel and electric can save energy consumption, but also their transport capacity can be enhanced.

2.2.3. *Civil aviation*

Since the 1990s, China's civil aviation demand has been expanding with a double-digit growth rate [32]. During the period 2003–2007, the share of civil aviation for the total social energy consumption in China has skyrocketed which is going from 6.99% to 8.05% [19]. Fig. 8 shows the energy consumption of the civil aviation in China from 1960 to 2009.

In future, the total fuel consumption of China's civil aviation will grow for a long time. In Ref. [20], it is forecasted that with the scenario of "Business as Usual", China's civil aviation fuel consumption will be 40.77 Mt in 2025. According to Energy Research Institute (ERI) data (see Table 5), between 2015 and 2030, the energy consumption of China's civil aviation will have a 5.99% average growth rate. Such a growth rate is much larger than that of other three transport sectors.

In China, the average utilization rate of passenger seats in all scheduled flights is small. In Ref. [34], it is reported that the

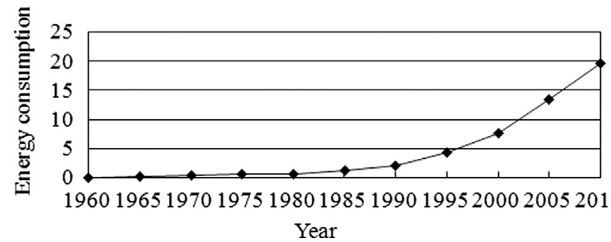

Fig. 8. Energy consumption of civil aviation in China (unit: 10^6 t standard coal) [33].

production capacity for diesel freight airlines in China had dropped gradually since 1992, to 78%, 72%, 63% and 59% in 1992, 1993, 1994 and 1998, respectively. However, the average energy intensity of China's civil aviation had reached 0.446 and 0.461 kg of aviation kerosene per tkm (tonne-kilometers) in 1993 and 1998, respectively. This means that the energy intensity of the civil aviation is much higher than that of China's railway and road transport.

The development trend of China's civil aviation is to open up direct route, optimize flight control with the application of flexible flight scheduling mode and employ new energy saving aircraft power system. For examples, in 2009, with some new direct air routes opening up, 88,000 tons jet fuel was saved, and 275,000 tons carbon dioxide emissions were reduced [35]. In 2010, China's airlines used temporary routes for over 250,000 vehicles, and this measure helped China to reduce 10.8 million km flight distance, save 58,000 tons jet fuel and decrease 183,000 tons carbon dioxide emissions [36].

2.2.4. *Waterway transport*

In the aspect of China's waterway transport, bunker oil and diesel are two main types of fuel oil. According to related statistical data, from 1990 to 2003, comprehensive unit consumption of the waterway transport in China had reduced from 138.6 kg standard coal/ten thousand converted ton-kilometer to 90.4 kg standard coal/ten thousand converted ton-kilometer [37]. The energy consumption of China's inland waterway transport is about 20% higher than the same consumption in advanced countries in 2008 [38]. Some scholars estimated that in 2005, the volume of China's commercial waterway transport oil consumption was about 13.5643 million tons after adding the non-operating waterway transport consumption [39].

Fig. 9 shows the energy consumption of China's waterway transport from 1980 to 2006. In Fig. 9, it is obvious that the energy consumption of waterway transport has been increasing from 1980. After 2003, the energy consumption of the waterway transport has a higher growth rate. From 1980 to 2006, it is always larger than that of the railways and civil aviation, but is much smaller than that of the highway transport. In the future, as presented in Table 5, from 2015 to 2030, the energy consumption of China's waterway transport will increase with an average growth rate of 1.33%. Such a growth rate is smaller than that of the other three transport sectors of China.

In Ref. [34], Li et al. analyzed the energy consumption of the waterway transport in China. It is reported that the diesel engines drive 95% of all ships in China, among which the low-speed diesel motors account for 88%. It is generally regarded that the fuel consumption of the low-speed diesel motors is 5–10 g/hp/h which is less than that of medium speed motors. Further, Li et al. concluded that low-speed diesel motors will be constantly improved in China in the future.

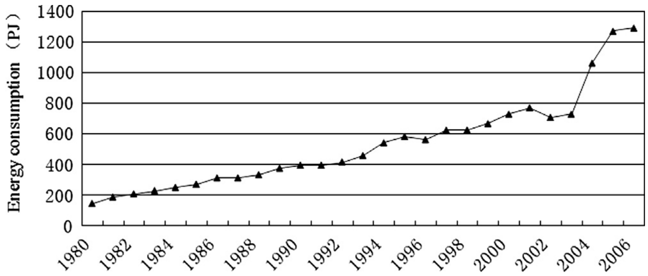

Fig. 9. Energy consumption of China's waterway transport [1].

3. Technology of China's transport energy saving

3.1. General technology status

3.1.1. Outline

China's fuel economy level is less than that of Europe, Japan and America. The fuel consumption per 100 t-km in China's road transport is twice more than that of the developed countries in the world. Energy saving by means of advanced technology is a major way for China's transport sector. These technologies not only include transport equipment, infrastructure and communication, but also involve administration measurement, such as constructing comprehensive transport system. In Ref. [40], it is estimated that advanced technologies and rational energy strategies can enable China to meet its economic development, energy security and greenhouse gas mitigation targets at least the next 50 years.

Nowadays, major technologies of China's transport sectors are emphasized on the aspects of intelligent transport, modern logistics, and information technology, for example, intelligent transport systems (ITS), public transport information service system, the Global Navigation Satellite System (GNSS) and so on. In addition, China is promoting the use of advanced equipment, carrying out the demonstration and extension plan of new energy vehicle and exploring the applications of berthing vessels shore power technology.

In China's transport systems, although a number of technologies have been applied, the key technologies which have great influence on transport energy saving only involve a small number of them. For example, in road transport, automobile driving system and new energy vehicles are two key technology fields. Only if such key technologies are utilized through technology progress, China can enhance its energy utilization efficiency in its transport sector

3.1.2. Key technologies in different transport sectors

3.1.2.1. Road transport

3.1.2.1.1. Automobile's driving system. To car's driving system, engine is the core part affecting car's overall performance. In China, many engine energy saving technologies have been developed and applied, which include engine lean burn, fuel stratified injection, electromagnetic valve driving system, E-GAS electronic throttle technology, etc. [41]. To improve the efficiency of driving system of automobiles, the effective power of the engine must be converted into driving power by transmission system, and the ways to increase the efficiency of driving power include the application of fuel-saving automatic clutch, mechanical multi-speed transmission and continuous variable transmission technology, etc.

The technology transition of energy saving for transport power system is necessary. In China, the technology transition pathways of energy power system include expending the use of gaseous fuel, developing and promoting the hybrid technology, and focusing on the research and development and demonstration of fuel cell vehicles and the hydrogen energy technology [42]. A common consensus is that the power must be diversification and electrification.

Propulsion system is also a key part for vehicle power system. Its core technology is the control strategies and the control system. As discussed in Ref. [43], the control strategy is very complex which is one of the key technologies for the hybrid propulsion control system. It is demonstrated that the hybrid electric bus based on the efficient-first control strategy can save the fuel consumption of about 27.3% in comparison with the conventional public bus in China's Wuhan [43].

3.1.2.1.2. New energy vehicles. In China cities, some technologies of alternative fuel vehicle actually have been applied, such as the compressed natural gas (CNG), methanol and dimethyl ether (DME) bus technologies. The hybrid electric vehicle and fuel cell bus technologies are also in varying stages of demonstration or deployment [44].

For electric vehicle, in recent years, because of the technology and cost barriers, its development has been relatively slow in the world [4]. So some groups begin to focus on exploring other pathways. For example, the group of electric automobile key projects put its efforts on the development of entire-car technologies [45]. Here three types of electric vehicles are studied, i.e., the fuel cell-powered, hybrid electric, and pure electric vehicle (including the solar power vehicle), and the development of three types of key technologies, including multi energy power train system, electric drives, and high power batteries. In addition, for electric buses, CO_2 capture and storage (CCS) is a potential method to reduce about 65% of GHG emissions when compared to diesel bus [44].

In China's road transport sector, a few great works have been done to develop energy saving technologies and extend the application of alternative vehicle fuel. In 1981, China started to study producing bio-diesel from rapeseed oil and cottonseed oil. In the late 1990s, China started to study electrical vehicles. In 2005, the First Auto Works (FAW) group began producing HEV. In 2006, the Dongfeng group launched 20 independently developed HEV buses in Wuhan [4]. An electric bus with super-capacitors as unique energy storage is produced in Heilongjiang province in 2005 [46].

3.1.2.2. Railway transport

3.1.2.2.1. Transport equipment. For the power supply system of trains, providing good infrastructure equipment and adopting advanced technology are the important ways to reduce the energy consumption of mobile devices. In China, the key energy saving technologies include following several aspects: energy recovery and conduction, distributed power supply system, development of electricity electronic systems with high-capacity, and great development potentiality of regenerative braking and energy storage systems [47].

Energy saving of air conditioning is also important for railway transport. As summarized in Ref. [48], the concrete technology measures in China include: (a) change the top supply air-flow organization into bottom supply, not only to improve the quality of air around passengers, but also to improve energy efficiency. (b) The plate-fin heat exchangers are used to retrieve energy from the exhaust air for pre-heating or pre-cooling the fresh air, it can save nearly 20% of electricity consumption in air-conditioned train. (c) Effectively air-conditioning system adjustment schemes are put forward to reduce using time of refrigeration and heating equipment based on temperature.

In China, the new modular integrated traction system (MITRAC) Energy Saver provides a way for its railway transport sector to save its energy consumption. It boosts the already established environmental advantage of public rail transport. The proven energy savings of 30% by the light rail vehicle (LRV) prototype and the corresponding emission reduction is in line with various local and global energy saving programs [49].

3.1.2.2.2. Energy saving technology of train operation. In general, as the traction engine, vehicles, lines, and some operation as well as administration situation are given, improving the locomotive handle method is an efficient and direct viable energy saving option. In China, many train operation modes and applied computer technologies have been summarized to research and develop train's optimization operation microcomputer guidance system, microcomputer control system and operation simulation system, etc.

To such a problem, a number of studies have been done in the domestic and foreign related reports. Their findings have great significant for China. For example in Ref. [50], Liu et al. proposed an analytical approach for calculating energy consumption and journey time trade-offs, and their particular attention was given to the mathematical description of train trajectories using differential equations. Howlett et al. use a new local energy minimization principle to calculate optimal switching points when a train traveling on a track [23]. To model train movement, the computer simulation was applied. For example, some researchers used the dynamic coast control to explore driving strategy [51], and many other researchers put their focus on driving techniques and minimizing energy consumption for freight trains [52,53].

3.1.2.3. Waterway transport

3.1.2.3.1. Optimization design of ships. Ship energy saving has become an important research topic of shipping industry in the world. This is because that ship energy saving is related to fuel saving resource and cost, environment protection and economic benefit, etc. [54]. The key technologies for ship energy saving adopted in China include the optimization design of ships, the optimal matching of ship, engine, propeller and rudder, and the power device etc. In general, when the environment condition meets the ship's use requirements, optimizing the design of hull lines and selecting fuel efficient main engine can make the whole ship matched and harmonized. Further, the propulsive efficiency can be improved, and the fuel consumption and operating costs can be reduced [22,55,56].

3.1.2.3.2. Optimizing ship's power instruments. Optimizing ship's power instruments is one of the important measures for ship saving energy. Here main technologies and measurements include the following several aspects: developing high efficient engine and new fuel additives, making use of main engine's exhaust gas for saving energy, utilization of electronic fuel injection system, discharge diffuser and shaft generator system energy saving technology, optimizing arrangement of engine room and improving the air inlet environment of main engine [41].

3.1.2.4. Civil aviation. In China's civil aviation sector, both the development level of science and technology and the quantity and structure of air transport cannot meet the reality transport demand. Metallic material and precision casting are the technology bottlenecks in the manufacturing process of engine. These bottlenecks confine the future rapid growth and improvement of civil aviation products.

At present, almost all of the airplanes and advanced equipments need to be imported. By October of 2010, there are about 1636 registered airplanes in China's civil aviation sector, in which only 18 airplanes were made in China [57]. This leads that in the technology field of China's civil aviation, more attention is about the repair and maintenance of existing airplanes. However, some maintenance enterprises are in small scale whose maintenance capabilities are weak, and the level of technology and administration is low.

3.2. The potentials of technology

3.2.1. Outline

In the technology fields of transport energy saving, as a whole, China is lag behind some advanced countries. For example, in China, fuel ethanol produced is not as good as it is in western countries on Well-to-Wheel (WtW) GHG emissions [58]. The average fuel consumption of engine in China was higher than the foreign ones over 10% [59]. In the aspect of energy efficiency, China also does not keep pace with some advanced countries. Y.Z. Li, the director of National Energy-saving Center, pointed out that China's motor vehicle fuel economy standards were lower than those of Europe, the United States and Japan [60]. Recent years, although domestic research levels of science and technology have been improved greatly, compared with that in Europe and America, the gap is still obvious.

However, China's transport systems also have some technologies which can catch up some advanced countries. For example, in the field of new energy vehicle, the technology gap between China and other advanced countries is small [45]. Compressed natural gas (CNG) and liquefied petroleum gas (LPG) are two relative mature technologies in China [44]. Apart from these, as described in Ref. [45], China has the capabilities to develop cells, electric machinery and driver for electric vehicles. In the late of 1990s, China started to research its electric vehicles. It is entirely possible for China to catch up the development of European countries.

The applications of new energy saving technologies need the support of consumer market. Only market demand can push the realization of transport energy saving. At present, such a pushing force is weak in China. For example, the Chinese government has made many efforts to promote the development of LPG buses. However, since no market supports such a demand, it is difficult to achieve success. Guangzhou city might be an example. Following the successful example of Hong Kong, Guangzhou now has 6400 LPG buses. But, bus companies have to face huge losses of profit due to the high LPG price which has risen with the raise of international oil prices [4].

In the future of China, in order to meet the realistic demand of transport energy saving, one of the major approaches is to develop advanced transport equipment. Enhancing the energy utilization efficiency is another way to decrease the transport energy consumption in which technology progress will play a key role, including advanced control strategies and administration measurements etc. From the long-term perspective, development and utilization of new energy will open a new path for China.

3.2.2. Transport equipments

To vehicle driving system, engine is the key part. It is reported that in China, the engine fuel shut-off strategy can save about 1–1.5% of the fuel consumption, and the optimized gear-shifting rules can save 6.7% of the fuel consumption [61]. To the future development of advanced engine in China, Wang et al. provided some suggestions [42]: (a) based on the new generation of highly efficient, clean and intelligent internal combustion engine, emphasis should be put on the breakthrough of the key technology of the hybrid power of the internal combustion engine (ICE)/electric motor/battery; (b) based on the natural gas engines, developing the hythane (a blend of hydrogen and natural gas with 20% or less hydrogen by volume) internal combustion engine technology and corresponding hybrid technology is recommended; (c) conduct the fundamental study and application development of key materials and parts of fuel cell, fuel cell stack and modules, focusing on developing a new generation of fuel cell engines and their hybrid power.

For new energy vehicles, in China's future, a key step is to provide the required fuel infrastructure (such as gas stations) and advanced alternative fuel vehicle technologies. Electric vehicle is one of the important new energy vehicles in China. At present, electric vehicle is generally regarded as the ideal mean of transport which has the most development prospect. But, it is still

limited by several development barriers, such as battery technology, high cost, little mileage range and inconvenient charging, etc. To the development of electric vehicle in future, some experts and scholars give some suggestions. For example, in Ref. [46], the development of an electric bus with super-capacitors as unique energy storage is outlined. The advantages of super-capacitor are quick charge, large power density and long cycle life.

From the viewpoint of development, modern light rail vehicles (LRVs) and Metros are good options for energy saving in China's urban rail transit system. These transport equipments can convert the mechanical braking energy of the train into electrical energy. Further, the produced electrical energy can be fed back into the catenary or the third rail. In Ref. [49], Steiner made a perspective of the energy storage system with Ultracaps for railway vehicles. According to Steiner's analysis, it seems to be a reliable technology solution with an enormous energy saving potential. The experiences of this system are also positive. Other transport equipments, such as linear induction motor (LIM), will be confined in the future for China. In Ref. [62], the energy consumption features of urban rail transit (URT) system and the energy consumption state of the operating LIM system are evaluated and analyzed. The shortcoming of LIM system is high traction energy consumption so that the widespread application of URT system in China is prohibited. In addition, as pointed in Ref. [63], the aerodynamic design of passenger train has been optimized over many years, hence, the potential for energy saving is virtually exhausted. Only a few details such as the pantograph or bogie can still be optimized.

3.2.3. *Efficiency of energy utilization*

3.2.3.1. Road transport. Advanced information system is very important for reducing the energy consumption of vehicles. With advanced information system, the data related to transport environment can be collected and processed timely, such as the intelligent transport system in urban transport. In general, intelligent transport system cannot only improve transport operating conditions, decrease congestion, but also improve fuel efficiency. To achieve the intellectualization of urban transport system, in the future, China needs to strengthen the development and application of information system, communication and other related technologies. Consequently, the efficiency of energy utilization can be enhanced.

Modern control technologies can enhance the energy utilization efficiency by a wide margin. In Ref. [43], Wang et al. studied the control strategy used in a hybrid electric public bus, and then proposed a torque-balancing control strategy. The results demonstrated that the hybrid electric bus could save approximately 27.3% on fuel consumption using their proposed control strategy. Pat et al. analyzed “business as usual” strategy which relies on coal combustion technologies [40]. The results indicated that such a strategy would not enable China to meet all of its environmental and energy security goals at least the next 50 years.

3.2.3.2. Railway transport. To the energy saving of China's railway transport, a common view is that optimizing transport power structure, enhancing traction efficiency, and raising the proportion of electric locomotive are three feasible ways to greatly enhance energy utilizing efficiency [64]. The application of alternative energy, the optimization of train operation, and the promotion of high-speed and heavy loading of passenger and freight transports are also the important measures for saving energy and enhancing energy utilizing efficiency.

However, enhancing the energy utilizing efficiency usually associates with rebuilding and reforming transport infrastructures. For example, in railway system, the rate of the energy utilization of electric locomotives is 30–32% which is higher than that of diesel locomotives (its energy utilization rate is only 25–26%) [64]. Since electric locomotives must run on electrified rail lines, speeding up the process of railway electrified reconstruction is an urgent task for China's railway in the near future.

3.2.3.3. Waterway transport. In China's future, to improve the energy utilizing efficiency of the waterway transport, inland river channels must be improved, and the mileage of deep waterway channel should be increased. In addition, for marine transport, large-tonnage and high-efficiency ships should be the major part in a transport fleet. For China's inland waterway transport, the integrated barge and push fleet should play their important roles. On the other hand, some advanced and mature energy-saving technologies should be used wildly, such as optimization and adjustment of main engine, economical speed, anti-drag of hull, implementation of reduction gear box and meteorological navigation, etc. [65,66].

3.2.3.4. Civil aviation. In China's civil aviation, the future development direction for energy saving is to improve the organization and administration levels, make full use of aircrafts and facilities, and reduce invalid transport. These technology measurements can enhance the energy utilization efficiency well. For example, increasing air layer density can help to increase traffic flow in the sky and decrease flight delay and traffic jams in air routes [24]. Perfecting air route network, optimizing transportation resources allocation, improving the utilization of aircraft, are also the effective measures for saving energy [67,68]. Optimizing the design of aircraft is another way for China's civil aviation to reduce energy consumption. For example, in the “bottle technology” project, if the aircraft wings can be designed from the perspective of aerodynamic, aircraft fuel consumption and carbon dioxide emissions will therefore be reduced by 20% [69].

3.2.4. *New energy resources*

Many types of transport fuel can be optioned for supporting the growth of transport energy demand in China. It is no doubt that in foreseeable future in China, petroleum gasoline and diesel will still be the major transport fuel. Some other liquid fuels (for example, the methanol and liquefied petroleum gas), the gaseous fuels (for example, the compressed natural gas), and alternative fuels (for example, the biofuels, hydrogen, and electricity) can also be used. Ou et al. compared and analyzed different transport fuels in detail [70]. Their conclusion should be a reference for China: (1) the fossil energy inputs are about 1.0–1.5 times the energy contained in the fuel for the corn-derived ethanol (CE), sweet sorghum-derived ethanol (SE) and soybean-derived bio-diesel (SB) pathways, but 0.5–0.9 times for the cassava-derived ethanol (KE), used cooking oil-derived bio-diesel (UB) and jatropha fruit-derived bio-diesel (JB) pathways; (2) compared with conventional petroleum-based gasoline and diesel pathways (CPP), the JB, KE and UB pathways can reduce both fossil fuel consumption and GHG emissions. The CE and SB pathways can only reduce fossil fuel consumption, but increase GHG emission. The SE pathway increases not only fossil fuel consumption but also GHG emission; (3) the main factors inducing high EC and GHG emission levels are high energy consumption levels and high fertilizer application rates.

Dimethyl ether production is a more recent technology, but is relatively untested in transport system. Dimethyl ether production has higher cetane rating and higher thermal efficiency. Thus, it has better fuel economy than petroleum-based diesel. Comparing to European countries, the proportion of diesel vehicles is very small in China. In addition, solar power is a kind of abundant resources, but it cannot be developed on a larger scale at present.

In China, gas vehicles have no technological barrier for large-scale application. However, gas resources in China are not very rich. Chongqing is one of the important natural gas producing

areas. Even in Chongqing, the supply of natural gas has also greatly limited for the further development of compressed natural gas vehicles. Therefore, in China, gas vehicles might be finally limited to some areas which have nature gas resource [4].

In addition, because electricity can be produced from coal, hydropower, or nuclear power, it has the inherent potential to be a large-scale energy source in China for the transport sector [71]. If future technological developments lead to batteries that provide cost-efficient mobile energy storage, electric propulsion can offer a significant alternative for consideration.

4. Policy analysis of China's transport energy saving

4.1. Outline

In order to release the pressure of the growing demand for fossil fuel energy, the Chinese government formulated and enforced some important laws and legislations, such as Energy Law (2007), Renewable Energy Law (2005), Medium-Long Term Planning for Energy Saving (2004), etc. In the meanwhile, some national-level policy frameworks were established to guide the central- and local-government's energy saving works in China's transport sectors, for example, Opinion on Encouraging Development of Energy-Saving and Environmentally Sound Small Displacement Automobile (2005) and the Administration Rules on Access to the Production of New Energy Vehicles (2007).

Recent years, the promulgation of some new policies and measurements effectively decrease the transport energy consumption in China. In the road transport, the execution of motor's fuel consumption standard effectively limited the use of high energy-consumption vehicles. For example, in 2004, the sale of ethanol gasoline was close to 80 million tons. In the railway transport, the comprehensive energy consumption obviously decreased, and the unit consumption of locomotive achieved better level. In 2005, the unit consumption of locomotive decreased 15% of that in 2000. In the waterway transport, in 2006, the unit consumption of four major shipping companies was 3.22 kg of standard coal/ton kilometer, which had a decrease of 15.9% compared to the same period. In China's civil aviation, between 1999 and 2005, the fuel consumption of each conversion ton-mileage decreased from 5000 kg to 3410 kg.

However, with the growth of China's economy, some related policies and measurements still likely confine the developments of transport energy saving. For instance, the operability of some laws and regulations are not strong, some standard systems of different transport sectors are not suitable for China's realistic developments.

4.2. Related policies

4.2.1. Laws and regulation

In the Energy Law (2007), the third chapter lists transport energy saving as a separated section. This section not only defines the subject of liabilities for China's transport energy saving work, but also presents the main development directions and approaches from the views of optimizing transport structure, giving priority to the development of public transport, enhancing the transport organization and administration ability as well as improving the energy utilization efficiency of traffic facilities. Actually, the Energy law only has guiding significance on the transport energy saving, its operability is poor.

In the Renewable Energy Law (2005), only the 16th clause is related to the traffic and transport. To a certain extent, this clause may promote the pilots and popularizations of the clean-fuel project for saving energy in transport sector. However, since the implementation time of this law is not long, its execution effect is not clear at present.

Medium-Long Term Planning for Energy Saving (2004) presents some requirements on the energy saving in China's transport sectors. These requirements include: (1) transport sector is regarded as the key field of energy saving, which must be given full attention; (2) this planning not only continuously presents some requirements on the technology progress of transport facilities and the alternative fuel, but also emphasizes the importance of systematic energy saving. Almost all of those requirements take into account the transport energy saving problem from the view of system. They are obviously in connection with the development of transport industry. Moreover, these requirements conform to the administration characters of China's transport sectors.

For strengthening the energy saving and emission reduction administration, the Comprehensive Work Program for Energy Conservation and Emission Reduction (2007) gave several suggestions, such as giving priority to the development of public transport, speeding up the construction of bus rapid transit (BRT) and rail transit, etc. Overall, those suggestions that the program presented are rather general. Therefore, if China wants to achieve better effects in transport energy efficiency, some further specific policies and measures must be issued.

Opinion on Encouraging Development of Energy-Saving and Environmentally Sound Small Displacement Automobile (2005) is mainly aimed at the previous status that there are no related incentive policies in the central and local governments and some transport administration departments. This opinion presented some guidelines which are focused on the energy saving issues of the road transport. Based on this, it can be seen that the energy saving in road transport field has become the key point and important part in China's transport energy saving. The Administration Rules on Access to the Production of New Energy Vehicles (2007) has significant instruction function to the new energy vehicle industry's development in China.

In 2010, the Ministry of Finance and the National Development and Reform Commission of China implemented the Detailed Rules to Promote Energy-Efficient Cars for the Energy-saving Products Huimin (people-benefiting) Engineering. With the implementation for one year, there are two positive effects: (1) the proportion of fuel-efficient vehicles was raised greatly, and the use of energy efficient passenger cars was accelerated; and (2) the consumer market of fuel-efficient vehicles was expanded in China [72].

In 2011, the Interim Special Fund Management Measures for Transport Energy Saving was published by the Ministry of Transport and the Ministry of Finance of China, and 112 projects have been supported by the special fund with the total amount of subsidies of 250 million RMB (40.8 million US dollars). These supported projects have saved about 315 thousand tons of standard coal, 224 thousand tons of standard oil of alternative fuel, and reduced 1.138 million tons of CO_2 emission [73].

4.2.2. Taxes and charges

From April of 2006, China has revised and implemented a new system of vehicle consumption taxes. According to such a new system, the tax rate is based on engine sizes, i.e., the production of smaller and efficient vehicles will have lower tax rate. For motorcycles, the tax rate for engine sizes lower than 250 cc was reduced to 3%. Since September of 2008, China has changed its Car Consumption Tax. According to such a tax, the tax rate of 3.0L to 4.0L vehicles will increase to 25% from 15%, and the tax rate of 4.0L and above vehicles will rise to 40% from the current 20% [74].

In January of 2009, the State Council of China implemented a fuel price and tax reform [4]. The notice from the Ministry of

Finance and the State Administration of Taxation includes increasing the unit tax rate of fuel excise tax and adjusting the tax policy for fuel destined for special purposes. Meantime, it would raise the gasoline tax from the current RMB 0.2 yuan per liter to RMB one yuan and the diesel tax from RMB 0.1 yuan per liter to RMB 0.8 yuan [75].

In March 2012, the Tax and Fee Notice of New Energy Cars and Ships were issued by the Ministry of Finance, State Administration of Taxation and Ministry of Industry and Information Technology of China. According to this notice, the tax of energy saving cars and ships is reduced in half, and the tax of new energy cars and ships is free from January 2012 [76].

4.2.3. Financial incentive

Since 2001, China has launched a series of incentive policies to develop new energy vehicles. In 2006, the public policy Opinions on Economical Policies to Promote Urban Public Transport Priority was announced, it requires local governments to operate low fare public transport services [4]. Beijing firstly implemented this policy to operate low-price public service. From 2007 to 2010, Beijing provided 60% discount to ordinary bus passengers and 80% to student passengers.

In the early 2000, the Tax and Fee Reform Implementation Plan for Transport and Vehicle, which was formulated by the Ministry of Finance and original State Plan Commission of China, asked the central government to allocate RMB 300 million yuan to support the updating and reforming of old cars every year [77]. In June 2009, National Development and Reform Commission and Ministry of Finance made a new scheme. According to this new scheme, on the basis of original subsidy policy, the subsidy scope is further expanded, and its strength also is enhanced [78].

In May 2010, in order to promote the transport energy saving and emission reduction, Ministry of Finance and National Development and Reform Commission formulated the Detailed Rules to Popularize and Implement the Energy Saving Cars [79]. According to the implementation rules, the consumer who buys the energy saving car will get a one-time subsidy. The subsidy standard is RMB 3000 yuan per car. In addition, the fuel saving standard of cars were raised from October 2010 [80].

Apart from these, in 2008, China implemented the fuel economy labeling for passenger vehicles. The label, to be placed on the vehicle's window, displays fuel consumption estimates for highway, city, and overall average driving patterns [81].The aim is to promote consumer's awareness of energy saving.

4.2.4. Standard systems

Relevant standards such as the Comprehensive Energy Consumption Calculation Rules (GB2589-90) and Enterprise Energy Measurement and Testing Guideline (GB6422-86) were formulated. The Energy Saving Legislation of Road and Water Transportation were promulgated in 2007. In 2008, the Long-term Energy Saving Plan in transportation industry was formulated, which confirmed all objectives and tasks for 2015 and 2020. China also published two compulsive standards: the Limits of Passenger Transport Operating Vehicles Fuel Consumption and Measurement (JT711-2008) and Limits of Freight Transport Operating Vehicles Fuel Consumption and Measurement (JT719-2008) [82].

In 2004, China implemented mandatory regulations for fuel economy standard for passenger vehicle fleet (AQSIQ and SAC, 2004). In this standard, maximum allowable fuel consumption limits were set up. And, every individual vehicle model sold in China will be required to meet the standard for its weight class. In 2008, the standard targeting light-duty commercial vehicles was implemented (AQSIQ and SAC, 2006) [26].

Since 1999, administration systems and policy regulations for promoting gas vehicles have been established in 19 demonstration regions/cities in China. There are more than 300 thousand gas vehicles in China at end of 2005. More and more cities are joining the program [26]. Since 2001, China has issued more than thirty standards for electric vehicles. The range covers the battery electric vehicles, hybrid electric vehicles, fuel cell electric vehicles and their components [83].

Since March 2011, the Ministry of Transport of China carried out a scheme that all the new candidate vehicles applying for the operation qualification (including imported vehicles) must conform to the standard requirements of fuel consumption limitation. By the end of November 2011, 1.425 million tons of fuel was saved and 4.602 million tons of CO_2 emission was reduced by the implementation of the scheme [73].

4.3. Exiting problems of China's present transport policies

4.3.1. Road transport

In the aspect of road transport organization, the reality situation in China is that the dispersive transport enterprises, especially the freight enterprises, low level of scale transport organization and non-standard divisional market always lead to more vehicle empty running. Excess toll-gates in domestic road network result in more and more transport jams so that vehicles has longer idling period and more extra energy consumption. To these problems, although a series of policies and administration measurements have been taken in China, within a long time, it is possibly difficult for the Chinese government and related administration to solve them.

Some incentive policies for the development of new energy vehicle are weak in China [45]. And, part of them is always distorted. In addition, some policies which are taken in China always are uncertain. As the policy uncertainty is added to the market uncertainty, in the future, the development and market penetration efforts of new energy vehicles in China will be discouraged. Indeed, as discussed in Ref. [45], the shortages of the initiative development of new energy vehicles need the Chinese government to provide more supports.

Small displacement automobiles also face many complex market problems in China. Currently, small displacement automobiles could not obtain licenses or could obtain licenses but at an extra registration cost. Some analysis showed that its extensive application is in need of a long period. The reason includes some market factors, such as the government constrains, public acceptance, fuel prices, etc.

4.3.2. Railway transport

To China's railway transport, standardization system is very important. For example, in railway freight transport, a key step for transforming traditional railway to optimized modern railway transport is to establish the standardization system of the pallets, containers, handling equipments, etc. This standardization system can effectively increase the transport efficiency and decrease energy consumption of freight transport. However, China's existing standardization systems are not perfect which cannot meet the demand of modern railway transport [84]. This possibly confines the development of China's transport energy saving in the future.

During the construction of infrastructure, related energy saving projects cannot play exemplary role which can actually meet energy saving standards. Energy saving regulation confirms that the execution action of energy saving should be incented. Since there is no formal policy document, it is difficult to execute the provision for labor administration department. In addition, China's railway is a monopolistic industry in which the self excitation and competitive consciousness are weak. The railway ministry not only

acts as a government department, but also is an enterprise. This leads that the relevant energy saving policies are not presented in detail enough, and they are lack of supervision [85].

4.3.3. Waterway transport

In China's waterway transport, the energy saving is becoming difficult. In the aspects of shipping policy and regulation, main existing problems are as follows: (1) some of them are established from the perspective of industry guidance and administration. This leads to that lots of policies and regulations are lack of authority; (2) detailed rules for the implementation of energy saving laws and regulations are nonexistent; (3) encouragement policy for energy saving technologies and products is not enough; (4) related standards and technology rules in the aspect of ship energy saving are far from perfect. These problems become the main development bottles of China's waterway transport.

4.3.4. Civil aviation

The reform that government separates from enterprise's administration has made civil aviation enterprises detached from Civil Aviation Administration of China (CAAC). As a result, CAAC has no authority to administrate civil aviation enterprises. Taking this into consideration, CAAC issued No.117 order to abolish administrative regulations concerned with energy saving in 2003. On the other hand, CAAC's internal organization is changed owing to reform. The adjustments of the government function and administrative agency have weakened the administration ability of energy saving. This will has great impacts on the energy saving work in China's civil aviation.

In China's civil aviation sector, related standards and policies of energy saving and emission reduction have not been established [86]. Feasible statistical, monitoring and examining methods are also weak. Besides, duties are not clearly defined in the civil aviation industry due to the unsound organization structure for energy saving work. In addition, as inadequate investment in the technology research, it is difficult for China's civil aviation to complete the absorbing and innovating works of energy-saving technologies. For example, in the field of renewable energy, lack of coordination and consistence in policy at the national level limits the development of energy saving [87].

4.3.5. Other

It is well known that the Chinese government and related administration departments have implemented many policies and measurements to reduce China's transport energy consumption. However, in China, there is not a uniform department for managing these different transport systems. This results in that many existing policies carried out difficultly. Moreover, since lacking of co-ordination mechanism among the different administration departments, the efficiency of administration is not high.

Statistical data of transport energy consumption is the basis for policy decision-maker to make some policies and measurements. It must be able to represent realistic situation. However, in China's official data, transport energy consumption only includes some entities who are engaged in business transport. Other entities and individuals do not be included. No official data on the exact fuel consumption is complied the statistics of China.

In addition, most of the standard systems need to be further improved so that they can adapt to the change of new economic and society circumstances. For example, in 2007, the recommended national standard for bio-diesel, bio-diesel for mixed use in diesel, was approved. However, there is no mandatory uniform quality standard for bio-diesel produced in China. Quality differences still exist between the applications in vehicles and watercraft without inflicting mechanical damage [4].

5. Policy suggestions for China's transport energy saving

5.1. High energy-efficient transport mode

China's transport system needs be inclined to the railway and waterway transports which have larger transport capacity and smaller energy consumption. In future, the government and related administration departments should take varieties of measurements to increase the investment in the railways and inland waters, enhance the construction of railway and waterway network, and then put further effort to adjust and optimize the road structure and improve network service level so that an efficient transport system, in which the railway is dominant, and different transport modes are closely connected, gradually forms [88,34].

To develop high energy-efficient transport mode for China, some experts and scholars present many helpful suggestions. For example, based on the efficiency of energy consumption, Li et al. suggested that the policy for the future development of traction modes in China should be as follows: (a) despite the high initial investment, electric railway is still the best traction mode; (b) diesel traction should be limited, because of its relatively high cost; (c) though both thermal efficiency and transport efficiency of energy for steam traction are inferior, it should be retained in some regions [34].

Optimizing the allocation of transport resource has great influence on the supply-demand structure, operation efficiency, and energy utilization efficiency [89]. Rail transit is the ideal transport way for urban groups and big cities. For some economy developed areas, railway transport, especially high-speed railway transport, should be the main transport mode which needs to be developed greatly [90]. Waterway transport is a high-efficiency and environment friend transport mode. Its advantage is that it has large carrying capacity and low energy consumption. The south of China, especially the Yangtze River Basin, is suitable for developing waterway transport [91]. Civil aviation is one of the main transport modes for mid-long distance passenger and high value-added freight transport. And, road transport not only is the collective and distributive transport mode of other transport modes, but also can meet individual requirements. For the entire transport systems of China, a key step is to make the road transport system connect with other transport systems.

5.2. Transport infrastructure

Transport infrastructure is an important part of modern transport system. Reducing the energy consumption of transport infrastructures is an effective way to realize transport energy efficiency [6,92]. In China, the reconstruction of transport infrastructure needs to be further promoted. Firstly, the facilities along the railway and highway lines need to be reconstructed. Secondly, the comprehensive utilization of ports' renewable energy sources should be encouraged by constructing some infrastructures. Thirdly, the government and related administration departments should strengthen efforts to renovate and reconstruct the aviation airport facilities. Some old airport facilities with high energy consumption must be eliminated.

From the view of policy and administration, many existing transport equipments need to be eliminated and updated [6,93]. In the road transport sector, the Chinese government needs to increase the market share of low-power small cars. Meanwhile, the market share of diesel passenger cars should be appropriately increased. In the railway sector, the subsidy policy need to be continuously implemented to encourage the scrapping and updating of railway rolling stock with high energy consumption and high emission. In the waterway sector, the Chinese government needs to speed up the updating of old transport ships, eliminate

the single-hull oil tankers and dismantle the old ferry in rural areas.

5.3. Administration and control mechanism

According to the Energy Conservation Law and Environmental Protection Law, an urgent issue for the Chinese government is to establish and improve the law and regulation system of the transport energy saving, making them more operable. The connection between the national energy saving planning and sectional planning should be more coordinating. Meanwhile, these different transport sectors must cooperate with each other. The Chinese government and related administration departments need to support and guide such as cooperated planning among the different transport sectors.

The rational laws, regulations and policies is quite important for China's transport energy saving [26,94]. A highly effective method for the government and administration departments is to establish and improve the post-evaluation system of the laws, regulations and policies, and timely carry out the evaluation of their implementation effect. The Chinese government and administration departments should track, survey and feedback the policy implementation, adjust and perfect the relevant laws, regulations and policies. In order to push the realizing of transport energy saving, they also need promulgate some policies and measurements to promote the market demand.

In China, enhancing the level of transport administration and organization is critical for improving the actual loading rate, and achieving energy saving as well as reducing pollutant emission, such as implementing passenger transport interchange, optimizing inland shipping fleet and freight intensive administration, and improving the layout of passenger station, freight station, etc. [6,93].

5.4. Incentive policies

In China's transport systems, at present, the application of new energy vehicles and the administration of private car are two important issues which need to be improved by incentive policies. Fang et al. evaluated the benefits of the government subsidies for alternative energy public transit vehicles [95]. Their study indicated that altering the preference variable of economic/environmental benefits influences evaluated results, suggesting that the government maximizes social benefits while the budget stimulates the innovation of transit agencies. The Chinese government should consider a range of preference variables when making optimum proposals.

To the problem of how to manage private car, an effective way is to add the external social and environmental costs. As discussed in Ref. [96], these policies include stringent and expensive driver licensing and vehicle taxes, establishment of car-free zones in dense areas, promulgation of rules on the formation and operation of auto companies.

5.5. Standard systems

It is necessary for China to speed up the construction of the standard system of transport energy saving. Such a standard system needs to be considered from the viewpoints of administration, equipment, employment, maintenance and evaluation etc. For some existing standard system, it is necessary for the government and related administration departments to revise them. For example, the fuel efficiency standard and inland shipping technology standard need to be formulated and implemented as soon as possible. The market access and exit criteria which depend on the fuel consumption limit standard need be improved too. In the railway sector, in order to improve the transport efficiency and decrease energy consumption of freight transport, the standardization system of China's railway transport should be established, such as the standardization of the pallets, containers and handling equipments [97].

5.6. The role of the government

In recent years, the Chinese government and related administration departments have done many works on transport energy saving. However, most of their works were limited in the policy level of macro managements. No detailed local and industrial rules match the implementation of these policies, so that these policies cannot be put into practice. In this aspect, Chinese government should learn from the experiences of Japan and other developed countries, and takes its dominant function to promote the comprehensive and systematical development of transport energy saving. For example, the Chinese government should take the lead in establishing effective cooperation mechanism among different administration departments, and building related executive or implemented mechanisms in local and urban governments.

Advanced technologies achieving in laboratory should be transformed into realistic productivity with the help of market operations. Arousing the initiatives of different market entities would promote transport industry to achieve results in the field of energy saving, especially in the field of R&D and industrialization of new energy vehicle because of the automobile manufacturers' important role in market entities. In view of this, the Chinese government should make use of different economic incentive or punitive measures as guidance, establish and improve the market system of energy saving, such as set up an incubation platform for the R&D of energy saving technology, scheme a perfect emission trading system, and develop related supporting industrialization policies and financial and tax initiative policies.

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